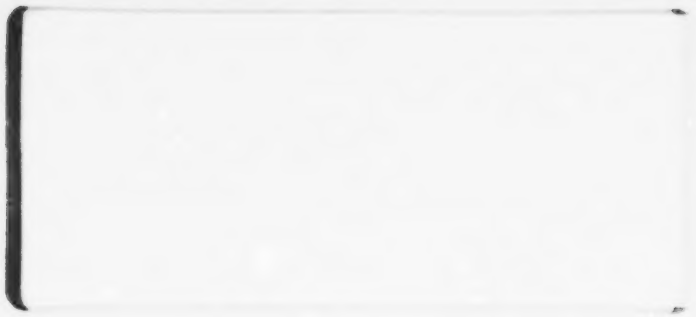

Manitoba
Environment
and Workplace
Safety and Health

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HEAVY METAL AND SULPHATE DEPOSITION IN SNOW, THOMPSON, MANITOBA 1982-1985

D. B. McEachern and S. F. Phillips

Terrestrial Standards and Studies
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ABSTRACT

Snow was sampled from twelve sites, within a 60 km radius of the Inco smelter in Thompson between 1982-1985. The purpose of the program was to monitor the deposition of heavy metals (Ni, Cu, Zn, Fe, Pb and Cd), sulphur and pH changes to the snowpack. Snow samples were collected in January, February and March of each year to measure the total winter accumulation of metals and sulphates.

Nickel and copper had similar distribution patterns; accumulation in the snow was highest at close-in sites, decreasing rapidly with distance to 12 km, where levels approached background. This implicated the smelter as a primary source of metals found in the snowpacks. Highest accumulation of metals in snow occurred at sites along the southeast transect, showing that deposition of heavy metals to snow is related to wind direction. Background levels of nickel and copper in snow were determined to be <1.0 mg/m^2. Even though iron deposition was similar to Ni and Cu it was a poor indicator of smelter emissions because of contributions from wind blown soil particles. Small amounts of lead, zinc and cadmium were also present in the snow but analytical data were highly variable and distinct patterns of deposition with distance were not evident.

Sulphate deposition to snow had distribution patterns similar to the metals, indicating that much of the sulphate found at close-in sites was derived from particulate smelter emissions. Background sulphate deposition ranged from 0.36 to 0.73 kg/ha. The pH of the snow was variable and showed no correlation with distance from the smelter.

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1. INTRODUCTION

In 1980 little information was available in western Canada concerning the environmental issue of acid rain or the long range transport of air pollutants (LRTAP). Serious environmental impacts were being uncovered in eastern Canada and the United States. In response, western Canada initiated regional and provincial monitoring programs. The objective was to provide scientific information on acidic deposition which is of concern because of the potential for ecological impacts on the environment.

In northern Manitoba there are non-ferrous metal smelters at Thompson and Flin Flon. The roasting of high sulphide ores at these smelting complexes releases large amounts of air pollutants (sulphates and heavy metals) into the atmosphere. These are deposited to the surrounding area. Forest studies by the Province of Manitoba are ongoing at both locations. The forest studies have demonstrated that deposition of heavy metals and sulphates to the soil has been occurring up to 35 km downwind from these smelters (Wotton and Hogan 1981, Hogan and Wotton 1984).

Snowpack monitoring has proven to be effective in evaluating pollutant deposition to the terrestrial environment (Phillips et al. 1986). In January of 1980, Environmental Management initiated a snow monitoring program around the Inco nickel smelter at Thompson.

The primary objective of the monitoring program was to provide information on heavy metal and sulphate deposition from the Inco smelter. These data will be used as an indicator of air

pollution distribution and accumulation in the terrestrial environment. This report focuses on the quantity of heavy metals and sulphates in snow between 1982-1985.

2. SAMPLE DESIGN

2.1 Sample Site Selection

Twelve snow sampling sites were selected in conjunction with previously established forest monitoring sites (Figure 1). The prevailing wind direction between November and March is from the west with strong northwest and north components (Figure 2). The primary dispersion zone for smelter emissions is therefore expected to be to the east and southeast of the smelter. Five sites were located along each of two transects, southeast (22 km) and south southwest (74.2 km) of the Inco smelter. The eleventh site was located south of the smelter and the twelfth to the northeast.

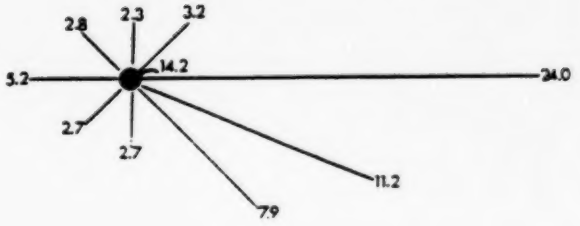
Sample sites were located on ice covered ponds or small bays of lakes. Sampling over ice was favoured because it minimized the amount of soil or other organic debris in the snowpack; choosing small ice covered water bodies helped to minimize drifting. Access was by helicopter or fixed wing aircraft.

2.2 Field Sampling

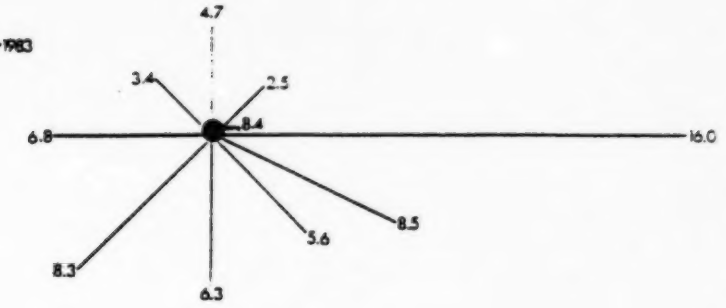
Each winter, snow surveys were carried out in January, February and March. Six snow samples were collected at each site on each visit. Three replicates were placed in acid prewashed 1 L linear polyethylene bottles and the other three in clean heavy gauge plastic bags.

FIGURE 1 Sample site locations - Thompson

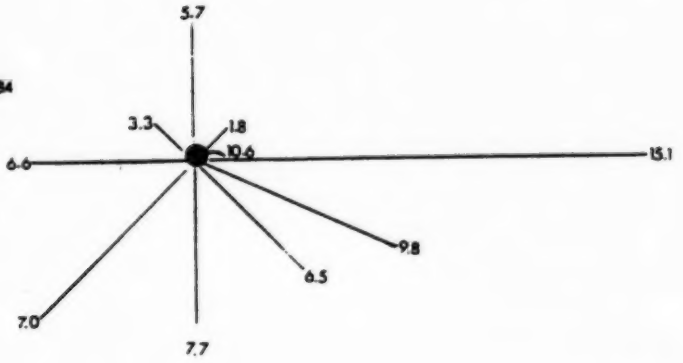
1981-1982



1982-1983



1983-1984



1984-1985

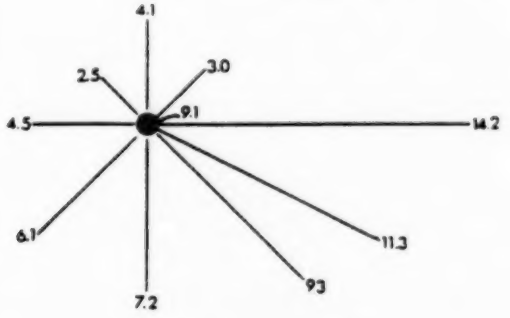


FIGURE 2: SMELTER PLUME DIRECTIONAL FREQUENCIES (%), THOMPSON, 1982-1985

In 1985 and 1986, snow cores were collected with an 80 cm^2 rectangular plastic scoop. A snow pit was dug with a plastic bladed shovel and one side was trimmed to a vertical face. Beginning at the top, a scoop of snow was removed by inserting the scoop horizontally into the face of the pit about 3.5 cm down from the surface. A second scoop full was removed immediately below the first and the process was repeated until the entire column was sampled. White ice at the snow-ice interface was rejected. All snow from each column was placed in one sample bottle (or bag). If the snow was deep, a column with a smaller surface area was sampled to reduce the volume of the sample. To facilitate this, the scoop was permanently marked at the 1/4, 1/2 and 3/4 positions along each side of its blade. When sampling, these marks were used as a guide and the scoop was only inserted part way into the snow. For example, to sample a 40 cm^2 column, the scoop was only inserted to the 1/2 mark on the blade.

Prior to 1985, snow cores were collected with an acrylic tube 1 m long and with an inside diameter of 3.7 cm . The tube was plunged into the snow pack and the snow in the tube was then compacted with a plunger. The tube was then lifted and the plunger was used to force the snow core out of the tube into a sample container. This method worked well except if there was an ice layer in the profile or if the snow was deep, in which case, some snow in the profile was missed.

After the samples were collected, bottles were sealed with a screw cap while bags were folded over twice and stapled. Coolers with ice packs were used to transport samples from the field to a laboratory freezer. Samples were kept frozen until just before laboratory analysis.

2.3 Laboratory Analysis

Samples were analyzed at the W. M. Ward Technical Services Laboratory (Man. Dept. of Environment and Workplace Safety and Health) in Winnipeg. Prior to analysis all bottles were weighed and acidified with 1 mL concentrated reagent grade nitric acid. Acidifying the samples keeps the metallic ions in solution after the snow melts. Bags were taken to the laboratory in batches of twenty. Each bag was weighed and placed in a plastic jug to support it in an upright position while the snow was melting; the folded and stapled top of each bag was cut off and the bag was heat sealed. Occasionally, sharp pieces of ice in the snow would puncture the bag; the contents of leaking bags were transferred to a new bag. These samples were flagged and the analytical results were checked closely for anomalies. After samples were melted, they were refrigerated until analyzed for major ions including sulphates, calcium, magnesium, sodium, potassium, nitrate and chloride as well as acidity and conductivity. Samples collected in polyethylene bottles were analyzed for total nickel, copper, iron, lead, cadmium and zinc.

Prior to each winter's survey, subsamples of plastic bags and bottles were tested to ensure they were free of chemical contaminants. Further testing of the chemical integrity of the bags was done by taking blank bags into the field during each sampling survey. On return, distilled water was placed in the blank bags and one was analysed with each batch of snow samples.

2.4 Data Analysis

Although three surveys were conducted each winter (January, February and March), the March data is the most important since it provides a measure of total winter accumulation of metals and sulphates. For this reason only the March data is presented in this report.

Analytical data reported in mg/L (i.e. concentration) has been converted to deposition units (i.e. mg/m^2) using the formula:

$$D = C \times \frac{V}{A} \times 10.0$$

Where D = deposition in mg/m^2

C = concentration of metal or sulphate in the melt water mg/L

V = volume of water (mL) obtained from the snow sample, based on the weight of the sample (ie 1 gm = 1 mL)

A = area of the scoop (cm^2)

10.0 = a constant for conversion of mL to L and cm^2 to m^2

Sulphate deposition was further converted from mg/m^2 to kg/ha using the formula:

$$S = \frac{D}{100}$$

Where

S = sulphate deposition in kg/ha

D = sulphate depostion in mg/m^2

100 = a constant for conversion of mg/m^2 to kg/ha

The mean deposition for each metal and sulphate at each site was calculated by averaging the March results for the three replicates from each site.

The mean pH was calculated by first converting individual pH readings to $[H^+]$ (hydrogen ion concentration; equiv/L) using the relationship:

$$pH = - \log [H^+]$$

and solving for $[H^+]$; $[H^+] = \text{antilog} (- pH)$

The mean hydrogen ion concentration was calculated for each set of three replicates and the mean converted back to pH.

3. RESULTS AND DISCUSSION

3.1 Metals

Six metals, iron (Fe), nickel (Ni), copper (Cu), lead (Pb), zinc (Zn) and cadmium (Cd) were selected for analysis based on the composition of emissions determined during annual stack testing (Appendix I). In summary, from 1981 to 1984 inclusive, the ranges in percent metal composition were 16.6 to 25.6% for Fe, 4.7 to 5.8% for Ni, 0.5 to 2.4% for Cu, 0.09 to 0.42% for Pb, 0.10 to 0.26% for Zn and 0.02 to 0.03% for Cd. Since there is variability in percent composition of the emissions from year to year there is probably also variability from month to month. If this is the case, some of the differences in the proportion of each metal found in the snow pack may occur because the actual wintertime composition is different than the stack testing results.

Even though iron has the largest percentage composition in the stack emissions, it may not be an accurate indicator of deposition to the snow pack. The amount of iron deposited to the snow tends to be highly variable compared with nickel and the ratio between iron and nickel is often lower than in the smelter emissions. Because of the consistency in the distribution patterns between Ni and Cu and other metals (except Fe) contained in the stack emissions, Ni and Cu appear to be good indicators to use in determining local deposition of Inco smelter particulates.

The general distribution pattern of Ni and Cu are similar; amounts in the snow were highest at close-in sites and decreased rapidly to a distance of about 12 km. This indicates that the smelter was the main source of the metals found in snow.

Wind patterns are important in determining the probable sources of solutes in the snow (Laird et al. 1986). In Thompson deposition was related to wind direction. Between November and early March (snow accumulation period for this study), winds were most frequently from the west, with strong northwest, north and northeast components. These winds carry the plume primarily to the east and southeast and secondarily to the south and southwest (Figure 2). For this reason the highest amount of metals in the snow were usually found at close-in sites along the southeast transect.

3.1.1 Nickel

Nickel deposition reflected to some degree the reported quantity of particulate emissions each year. The highest emissions

were in 1982 and the lowest in 1983 when the smelter was shut down from November 1, 1982 to January 31, 1983. The wintertime emissions in 1983 were only 22.9 t (tonne) or less than 10% of the total for the same period in 1982 (295.9 t) (Table 1).

The amount of nickel in the snow was also highest in 1982 and lowest in 1983 (Figure 3 and Appendix II). However, the levels of deposition at sites 10 and 11 (1.4 and 2.0 km SE, respectively) appeared to be unusually high in 1982. In 1984, emissions were 250.3 t (16% lower than 1982) yet the deposition at site 11 was 85% lower than in 1982. The correlation was similarly poor for site 10 in 1982 and for both sites in 1985. Another difference which was noted in the 1982 data was that deposition was proportionally lower at the more distant locations (sites 5, 6, 7). This leads us to suspect that more of the particulate load in the plume may have been deposited early in its trajectory, possibly due to lower wind speeds, different atmospheric mixing conditions or maybe larger emission particles. Compared with 1984, the 1985 deposition of nickel to the snow was slightly higher at site 10 but was lower at sites 5, 6 and 7.

The SSW transect generally had lower deposition than the SE transect (Figure 3). However, in 1983, deposition was greater in the SSW direction. Wind directional frequencies could account for this difference because there was a greater frequency of NE winds than NW winds during that accumulation period (February 1, 1983 to March 9, 1983) (Figure 2).

Deposition of Ni to the snow was consistently higher at site 12 than at site 1 even though site 12 was only slightly closer to the smelter. Closer examination indicates that site 12 is in a WSW

Table 1: Particulate emissions (November-March), Inco Limited Smelter, Thompson, Manitoba, 1982-1985.

YEAR	PARTICULATE STACK EMISSIONS (t)
1982	295.9
1983	22.9*
1984	250.3
1985	178.7

* Smelter shutdown from November 1, 1982 to January 31, 1983

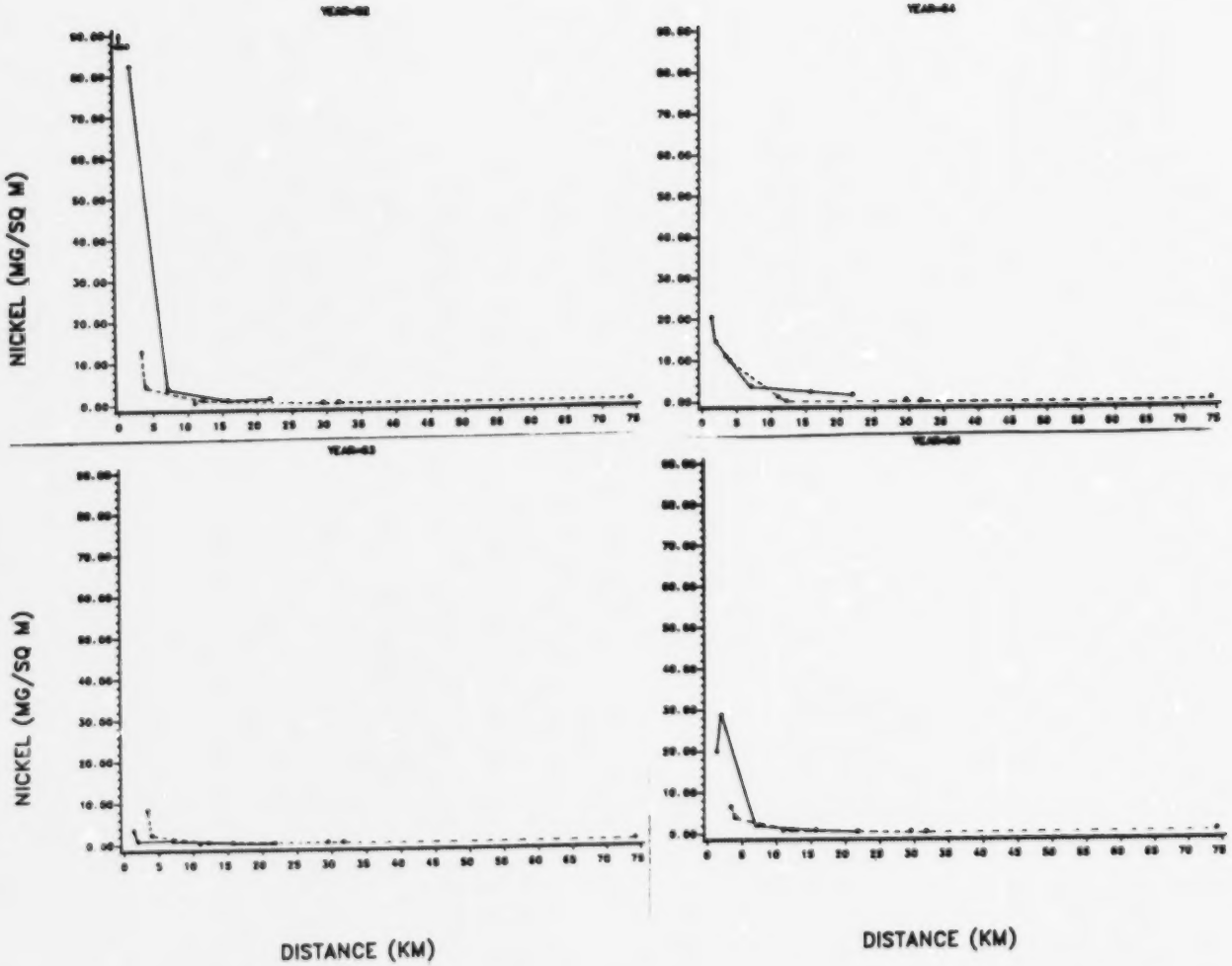


FIGURE 3: Nickel deposition to snow, Thompson, 1982-1985.

Southeast ———

South Southwest - - - - -

direction while site 1 was in between SSW and SW. In terms of plume dispersion this is a relatively large difference and could account for the differences in deposition which were observed.

It is also noteworthy that site 4 which is 11 km south of the smelter often had less Ni in the snow than sites at similar distances along the SE and SSW transects. It appears that dispersion of the Inco smelter emissions may not be as strong directly to the south.

Deposition at site 3 (31.7 km SSW) was relatively low and similar to that at site 9 (74.2 km SSW). Since the distance from the smelter doubled but there was no further decrease in the amount of nickel in the snow, this indicates that both sites were influenced only by background nickel. Based on these data, the background range of Ni deposition in this area appear to be <0.5 mg/m^2. Site 13, 29.5 km NE of the smelter, was also within the background range. Wintertime winds seldom blow in that direction.

3.1.2 Copper

The deposition pattern of Cu to the snow was consistent with that of nickel (Figure 4 and Appendix III) but was usually lower, reflecting the lower percentage composition in the stack emissions (Appendix I). In 1982 however, the amount of Cu in the snow was equal to or higher than Ni. Based on these data we suspect that there may have been a larger proportion of Cu in the smelter emissions between November 1981 and March 1982. However, information on the actual emission composition for that time interval is not available.

Background deposition of Cu was similar to that of Ni i.e. <0.5 mg/m^2. However, in 1985 Cu deposition at site 9 was four times higher than other years and twice as high as site 3. Ni was also abnormally high (double background) at site 9 in 1985. So far we have not been able to account for these anomalies.

3.1.3 Iron

Overall, Fe deposition was quite variable. However, the deposition of Fe was similar to Ni and Cu in that iron was highest at close-in sites, decreasing rapidly to a distance of 12 km (Figure 5). This indicates that the smelter was the source of at least some of the Fe in the snow.

Background concentrations were higher (<5 mg/m^2) than for Ni and Cu (Appendix IV). Sites 3 and 13 which had background levels of Ni and Cu, sometimes had high iron deposition (≥13 mg/m^2). These sites may have received higher amounts of soil dust which may contain substantial amount of iron.

Iron deposition at close-in sites along the SE transect was lower than Ni or Cu in 1982 even though Fe made up 24% of the emissions compared to only 5.4% of Ni and 1.0% for Cu. Similarly Fe deposition was only slightly higher than Ni in 1984. On the other hand, Fe at sites 10 and 11 was closer to the expected amount in 1983 and 1985. The variation in iron deposition from year to year may be related to variations in the iron content of the smelter emissions.

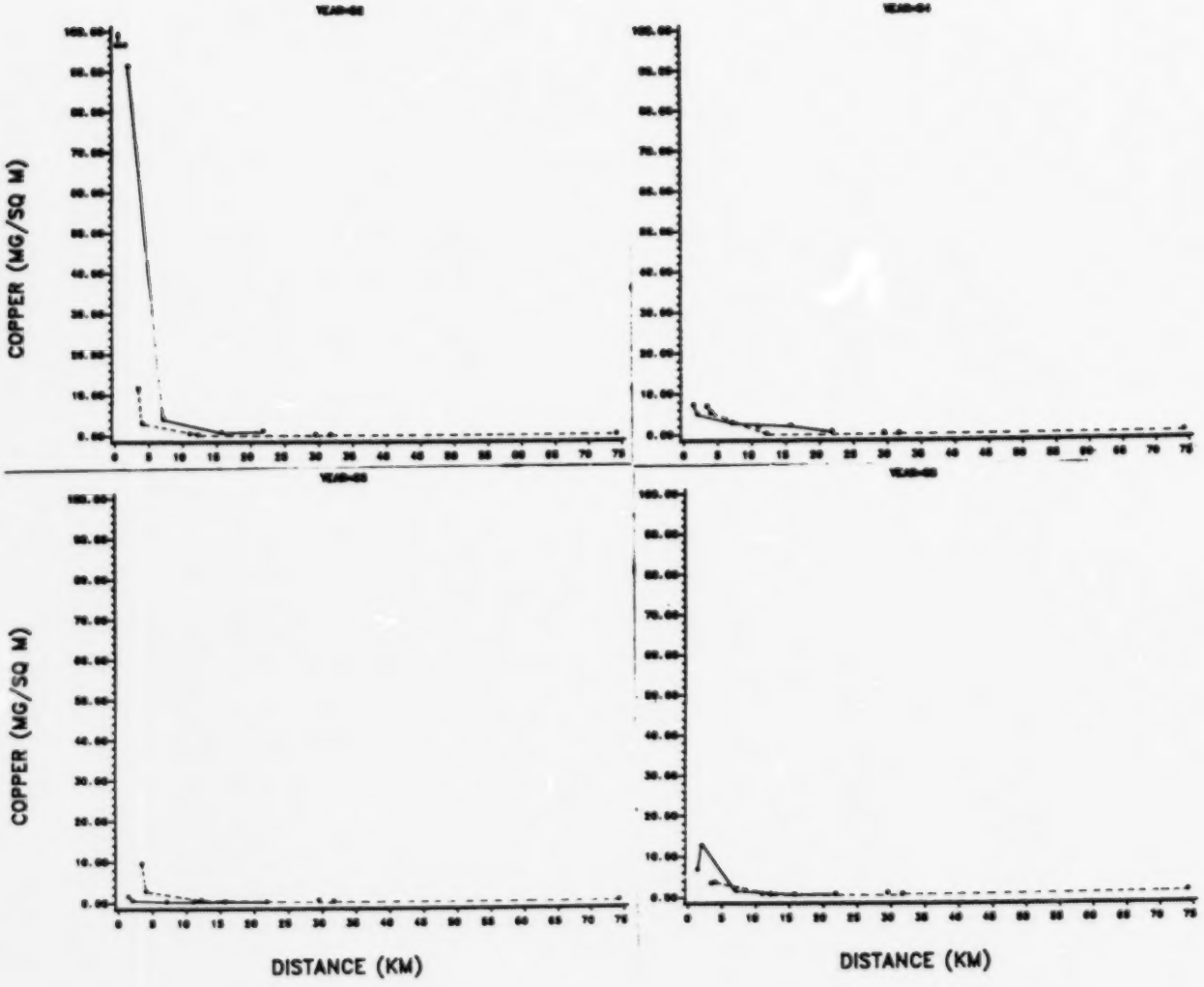


FIGURE 4: Copper deposition to snow, Thompson, 1982–1985

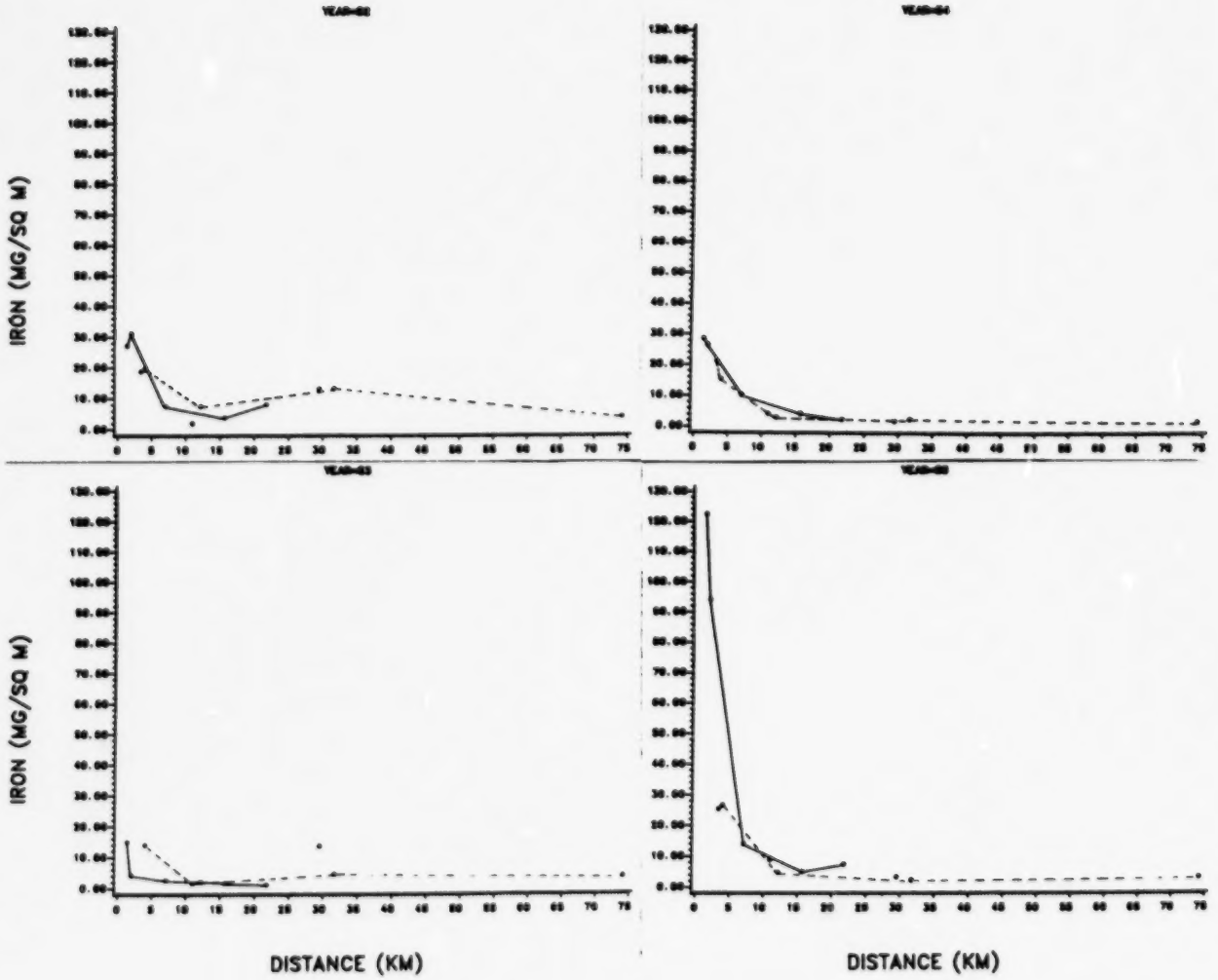


FIGURE 5: Iron deposition to snow, Thompson, 1982-1985

3.1.4 Lead, Zinc and Cadmium

Small amounts of Pb, Zn and Cd were also present in the snow samples but the data were highly variable and clear patterns of distribution were usually not evident (Figures 6, 7 and 8). Lead deposition was low (generally <1.0 mg/m^2) but did show a consistent trend of higher deposition at close-in sites indicating that it may have come from the smelter. On the other hand, Zn deposition was not correlated with distance or direction from the smelter even though the proportion of zinc in the emissions was only one third less than lead. To date, we have been unable to find an explanation for this apparent anomaly. Cadmium deposition was relatively low in 1984 and 1985 (mostly <0.15 mg/m^2) which was to be expected since it comprises only 0.03% of the particulate emissions. In 1982 Cd deposition was higher than in 1984 and 1985 but lower than in 1983. It is difficult to understand why deposition was highest in 1983 when total particulate emissions were so low. In any case, because the deposition is not correlated with distance from the smelter there is no indication that the smelter was the source of Cd in the snow.

3.2 Sulphate-Sulphur

Sulphate deposition had a similar distribution pattern to that of the metals, that is, it was highest at sites close to the smelter and decreased as distance increased. This implicated the smelter as the source of sulphate in the snow.

Sulphur is emitted in two forms, gaseous SO_2, and SO_4^{-2} anions which are combined with the metal ions in the particulates.

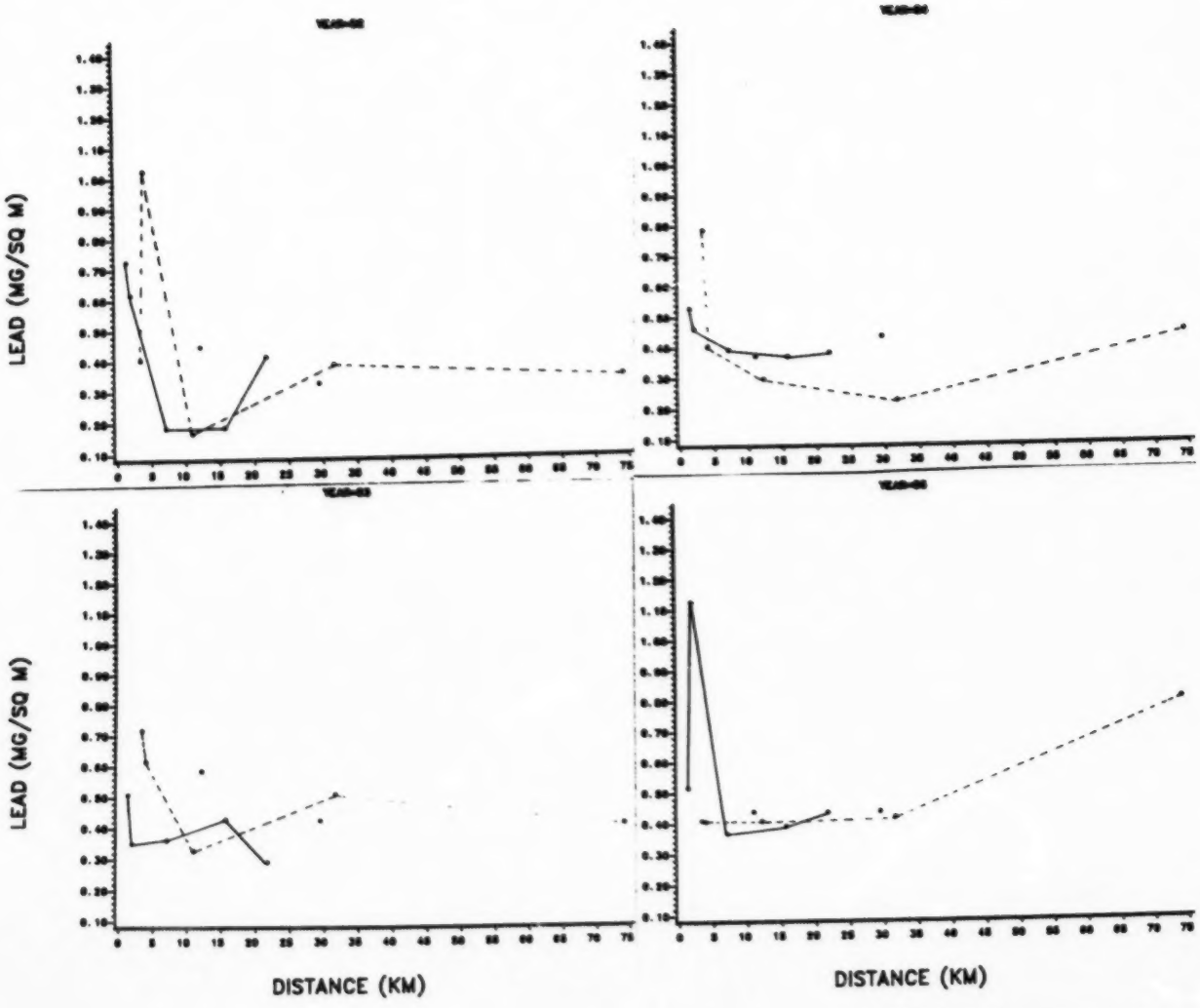


FIGURE 6: Iron deposition to snow, Thompson, 1982-1985

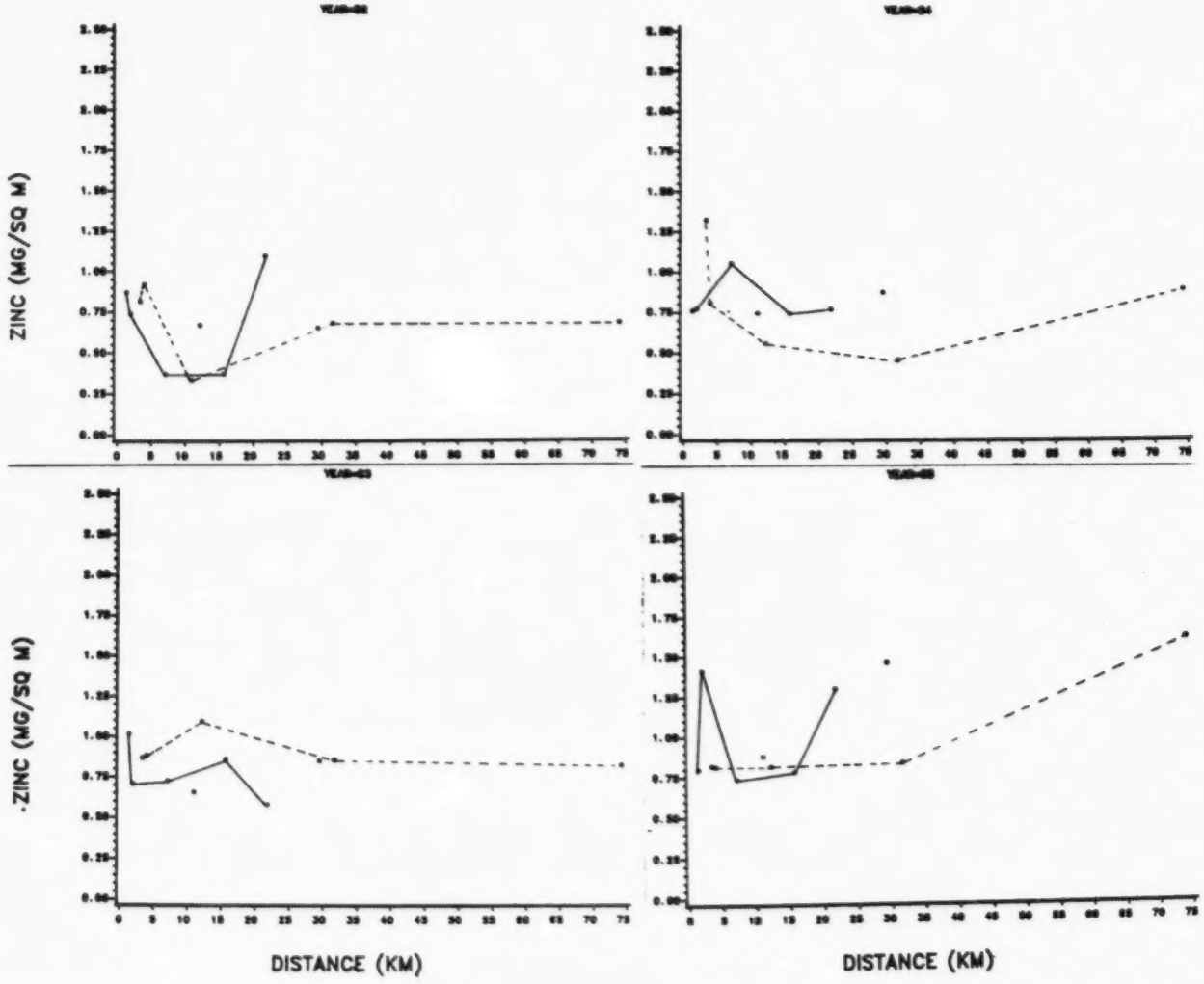


FIGURE 7: Zinc deposition to snow, Thompson, 1982-1985

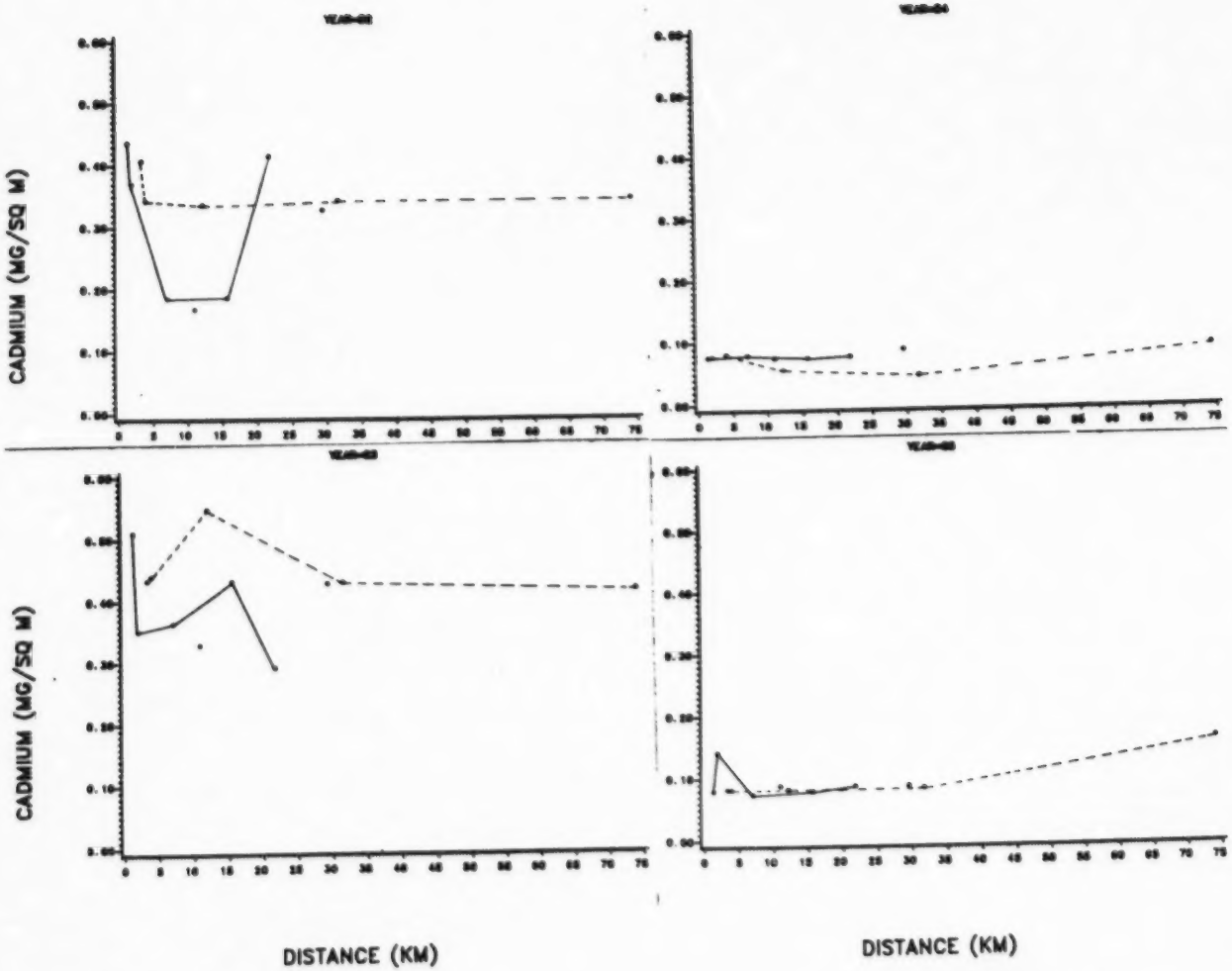


FIGURE 8: Cadmium deposition to snow, Thompson, 1982-1985

The accumulation of sulphate in the snow is a product of absorption of SO_2 and impaction of sulphate particles (Dovland and Eliassen, 1976). Sulphur dioxide is not subject to gravitational fallout and can be carried further away from the smelter. During its residence time in the atmosphere, SO_2 may be oxidized to SO_3 and may combine with water vapor to produce H_2SO_4. This form of sulphur is scavenged from the atmosphere by precipitation and in the winter months is combined in snow. SO_2 may also be adsorbed directly to the snow. SO_4^{-2} in the particulates is subject to gravitational fallout and are continually being added to the snow surface. Inco particulate emissions contain from 7.2 to 11.3% sulphur by weight (figures used in Inco's mass balance SO_2 calculations, see Appendix IX). It is likely that much of the sulphate which was found in the snow at close-in sites was derived from these particulate smelter emissions. This explains why the deposition pattern for SO_4^{-2} was similar to that for metals such as Ni and Cu.

Sulphate deposition at close-in sites along the SE transect was highest in 1982 and lowest in 1983 (Figure 9). The high deposition in 1982 supports the theory that particulate sulphate is important to the overall sulphur loading because particulate emissions were highest in 1982 while SO_2 emissions were lower in 1982 than in all other years except 1983 (Table 2). Both SO_2 and particulate emissions were low in 1983, because of the shutdown, which accounts for the low SO_4^{-2} deposition in 1983. The amount of SO_4^{-2} in the snow was lower in 1985 than in 1984 in spite of the fact that wintertime SO_2 emissions increased. However, this could be a

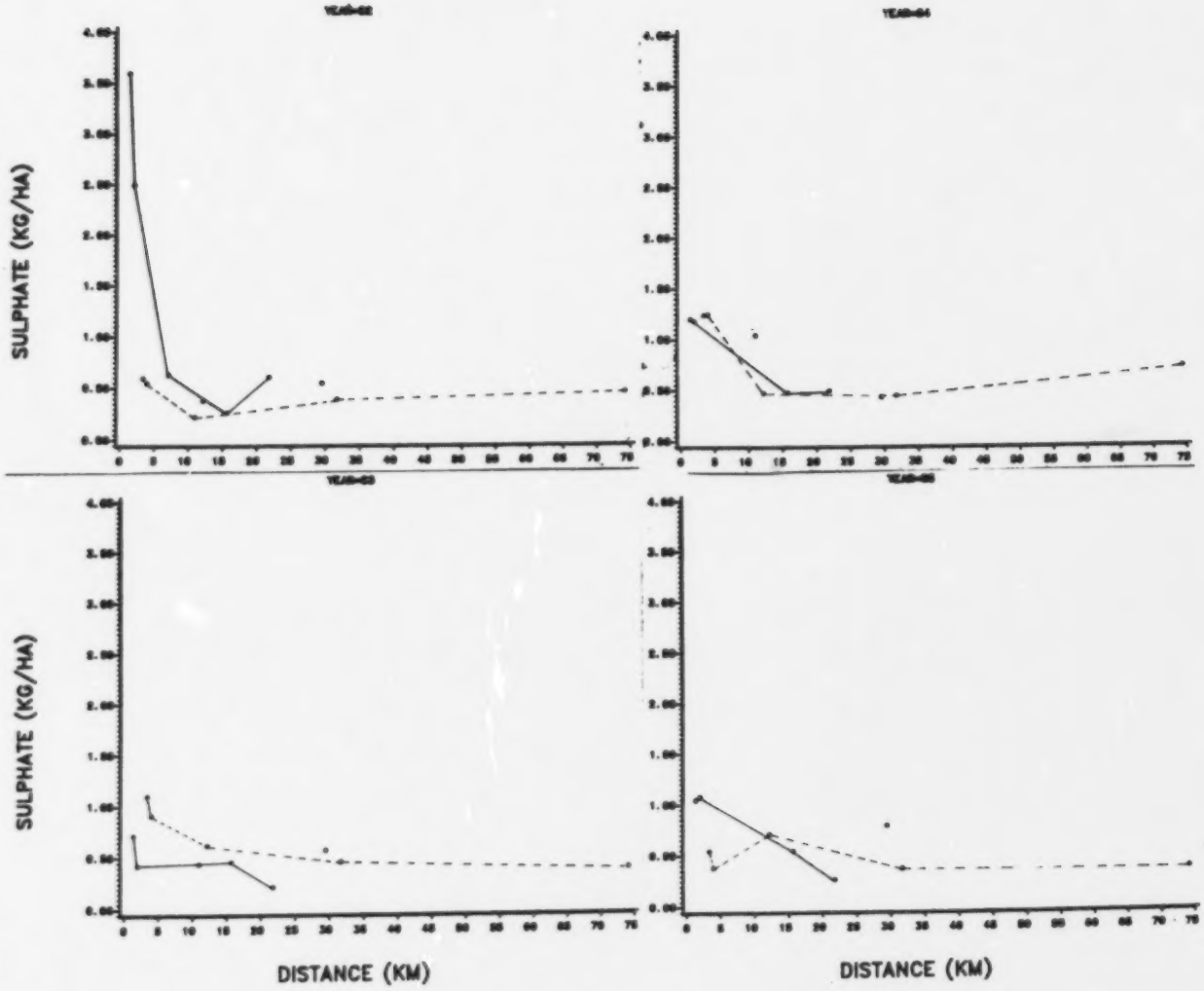


FIGURE 9: Sulphate deposition to snow, Thompson, 1982-1985

Table 2: Sulphur Dioxide (SO_2) emissions November to March, from Inco Limited Smelter, Thompson, Manitoba, 1982-1985.

YEAR	SO_2 EMISSIONS (tonne)
81/82	26,605.8
82/83	8,018.6*
83/84	63,345.7
84/85	71,683.6

* Smelter shutdown from November 1, 1982 to January 31, 1983.

reflection of the fact that particulate emissions were lower in 1985 than 1984.

The influence of wind direction on sulphate deposition was particularly evident when the 1983 data is compared with other years. The deposition was highest at site 12 in 1983 which was the year when smelter emissions were lowest and did not begin until February 1. The wind had a strong easterly component during the period from February 1 to March 9. However, during the snow accumulation period in the other years, the dominant wind frequency was SE. This explains why SO_4^{-2} deposition was higher in the SW direction than in the SE in 1983.

The background deposition of SO_4^{-2} ranged from 0.36 to 0.73 kg/ha over the 1982 to 1985 period. This was the same range found in analyses of snow from other areas of northern Manitoba, which were remote from the smelter.

3.3 Snow pH

The pH readings were variable and in most years did not show a correlation with distance from the smelter (Figure 10). From a purely theoretical perspective, pH should be indirectly correlated with SO_4^{-2} i.e. as SO_4^{-2} increases the pH should decrease. Since SO_4^{-2} was highest close to the smelter and decreased with distance, the pH should be lowest close to the smelter and should increase with distance. However this was not the case. One possible explanation is that some of the SO_4^{-2} may have been present as metallic sulphates which may not produce an acidic reaction.

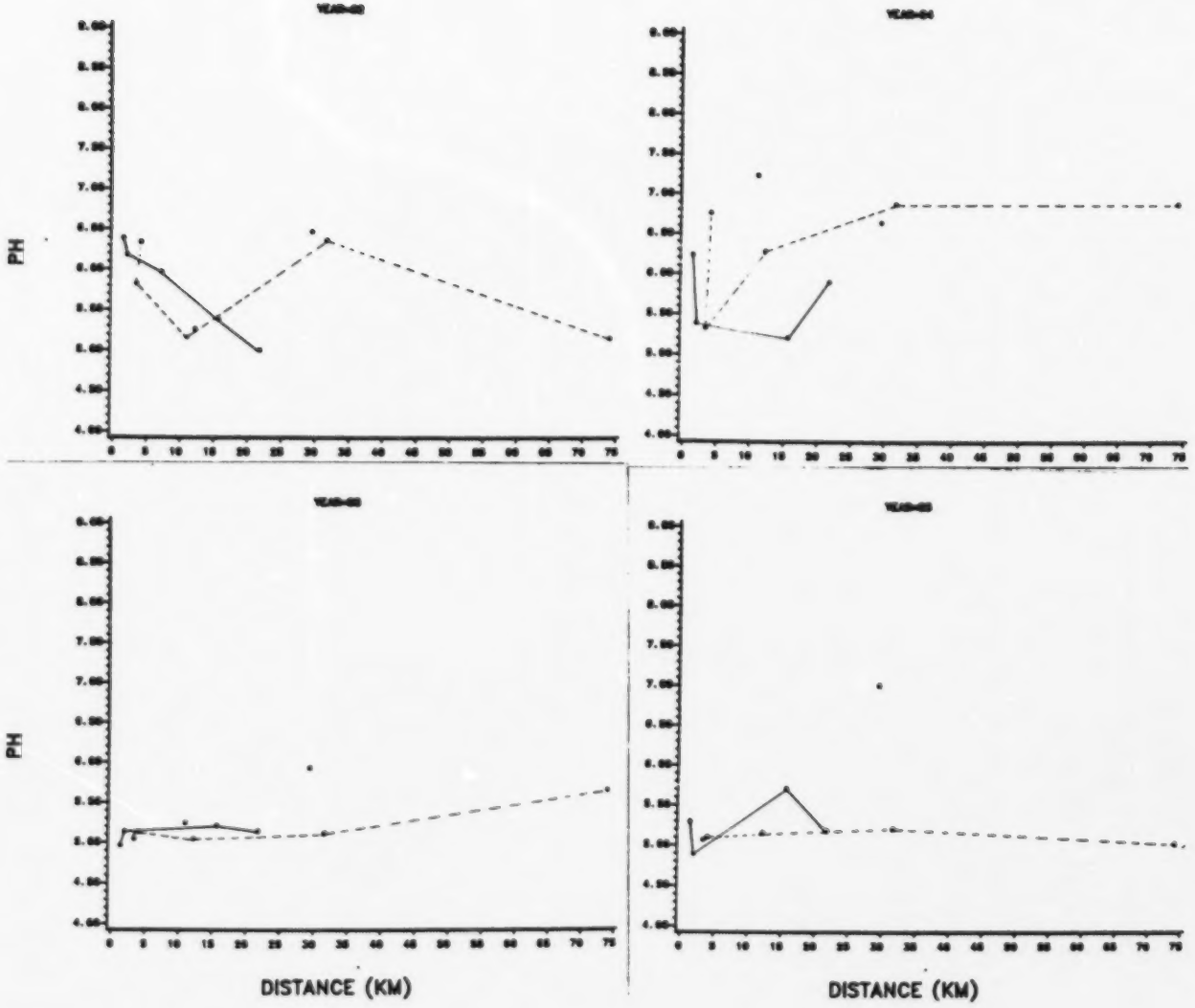


FIGURE 10: ph in snow, Thompson, 1982-1985

Secondly, it is possible that the particulates from the stack emissions are basic and thus may buffer the acidifying influence of SO_4^{-2} (Barrie & Whelpdale 1977). This could result in decreasing pH with distance because as the amount of particulates decreases, the SO_4^{-2} ions could become increasingly dominant. This may have been a factor in 1982 when the pH in the snow decreased with distance. Finally, because SO_2 is dispersed more widely than particulates, acidic producing sulphur oxides may be more evenly distributed in the local environment thus precluding the development of a pattern related to distance from the smelter.

The pH of the snow was generally below 5.6, but the data do not show that the smelter emissions are influencing snow pH. Over the four year period there were two samples with pH below 5.0, site 11 in 1983 (pH 4.96) and site 10 in 1985 (pH 4.89). These pH values are not expected to have a detrimental effect on environmental components in this area because the soil and geological characteristics of Thompson are within the moderate to low sensitivity category (Wotton & Haluschak 1985).

4. CONCLUSIONS

The pattern of deposition and accumulation of heavy metals in snow within 12 km of Thompson implicates the nickel smelter as the source. Metal deposition patterns were related to wind direction, with the highest deposition occurring at sites along the southeast transect. Background values for metals were found beyond 31.7 km downwind of the smelter. Background values for nickel, copper, iron, lead, zinc and cadmium ranged from 0.24-0.80 mg/m^2, 0.23-1.6 mg/m^2, 1.8-13.0 mg/m^2, 0.23-0.80 mg/m^2, 0.45-1.6 mg/m^2 and 0.05-0.43 mg/m^2 respectively.

Sulphate deposition had a similar distribution pattern to that of the metals, with background values ranging from 0.36 to 0.73 kg/ha. This is the same range for sulphate as that found in othere areas of northern Manitoba which are remote from the smelter.

The pH of the snow was variable and showed no correlation with distance from the smelter.

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APPENDICES

Appendix I: Percent composition of smelter emissions, Inco Limited, Thompson, Manitoba, 1981-1984

	Fe %	Ni %	Cu %	Pb%	Zn %	Cd %
August/1981	23.9	5.4	1.0	0.21	.14	.02
July/August, 1982	16.6	4.7	0.5	0.09	.10	.02
September, 1983	21.9	5.8	2.2	0.31	.24	.03
June, 1984	25.6	5.6	2.4	0.42	.26	.03

Appendix II: Mean nickel deposition (mg/m^2) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	135.8	3.6	20.4	20.0
2.0	(10)	82.4	1.0	14.6	28.7
7.1	(5)	3.9	1.0	4.0	2.0
16.0	(6)	1.1	0.43	2.4	0.83
22.0	(7)	1.4	0.29	1.7	0.49
South					
11.0	(4)	0.58	0.33	1.3	0.85
South-Southwest					
3.4	(12)	12.9	8.3	11.2	6.6
4.0	(1)	4.5	2.4	10.1	4.1
12.2	(2)	1.2	0.55	0.28	0.87
31.7	(3)	0.39	0.43	0.24	0.42
74.2	(9)	0.35	0.42	0.45	0.80
Northeast					
29.5	(13)	0.33	0.43	0.44	0.52

Appendix III: Mean copper deposition (mg/m^2) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	161.0	1.7	7.3	6.9
2.0	(10)	91.5	0.70	5.1	12.7
7.1	(5)	4.0	0.36	2.9	1.7
16.0	(6)	0.96	0.36	2.0	0.77
22.0	(7)	1.3	0.29	0.77	0.87
South					
11.0	(4)	0.71	0.36	2.2	0.88
South-Southwest					
3.4	(12)	11.7	9.7	7.0	3.5
4.0	(1)	3.2	3.0	5.4	3.8
12.2	(2)	0.47	0.75	0.30	0.82
31.7	(3)	0.34	0.43	0.23	0.82
74.2	(9)	0.35	0.42	0.43	1.6
Northeast					
29.5	(13)	0.33	0.72	0.44	1.2

Appendix IV: Mean iron deposition (mg/m^2) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	27.1	15.0	28.5	122.2
2.0	(10)	31.0	4.3	26.5	94.0
7.1	(5)	7.4	2.7	10.2	14.0
16.0	(6)	3.7	1.7	4.2	-
22.0	(7)	8.0	1.2	2.3	4.6
South					
11.0	(4)	1.9	1.7	4.2	8.6
South-Southwest					
3.4	(12)	18.7	-	21.0	25.3
4.0	(1)	19.4	14.2	15.4	26.6
12.2	(2)	7.4	2.2	3.0	4.7
31.7	(3)	13.0	4.6	2.4	2.2
74.2	(9)	4.2	3.9	1.8	3.2
Northeast					
29.5	(13)	13.1	13.7	1.7	3.2

Appendix V: Mean lead deposition (mg/m^2) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	0.73	0.51	0.53	0.52
2.0	(10)	0.62	0.35	0.46	1.12
7.1	(5)	0.19	0.36	0.39	0.37
16.0	(6)	0.19	0.33	0.37	0.39
22.0	(7)	0.41	0.29	0.38	0.43
South					
11.0	(4)	0.17	0.33	0.37	0.39
South-Southwest					
3.4	(12)	0.41	0.72	0.79	0.41
4.0	(1)	1.0	0.67	0.40	0.41
12.2	(2)	0.45	0.59	0.30	0.41
31.7	(3)	0.39	0.51	0.23	0.41
74.2	(9)	0.35	0.42	0.43	0.80
Northeast					
29.5	(13)	0.33	0.43	0.44	0.44

Appendix VI: Mean zinc deposition (mg/m^2)to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	0.87	1.0	0.76	0.80
2.0	(10)	0.74	0.71	0.77	1.41
7.1	(5)	0.37	0.73	1.1	0.73
16.0	(6)	0.37	0.86	0.74	0.77
22.0	(7)	1.1	0.58	0.77	1.3
South					
11.0	(4)	0.34	0.66	0.74	0.88
South-Southwest					
3.4	(12)	0.81	0.87	1.32	0.82
4.0	(1)	0.92	0.88	0.81	0.81
12.2	(2)	0.67	1.1	0.56	0.82
31.7	(3)	0.67	0.86	0.45	0.83
74.2	(9)	0.69	0.84	0.89	1.6
Northeast					
29.5	(13)	0.65	0.85	0.87	1.5

Appendix VII: Mean cadmium deposition (mg/m^2) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	0.43	0.51	0.08	0.08
2.0	(10)	0.37	0.36	0.08	1.14
7.1	(5)	0.19	0.36	0.08	0.07
16.0	(6)	0.19	0.33	0.07	0.08
22.0	(7)	1.41	0.29	0.08	0.09
South					
11.0	(4)	0.17	0.33	0.07	0.09
South-Southwest					
3.4	(12)	0.41	0.43		0.08
4.0	(1)	0.34	0.44	0.08	0.08
12.2	(2)	0.34	0.55	0.06	0.08
31.7	(3)	0.34	0.43	0.05	0.08
74.2	(9)	0.34	0.42	0.09	0.16
Northeast					
29.5	(13)	0.33	0.43	0.09	0.09

Appendix VIII: Mean sulphate deposition (kg/ha) to snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	3.59	0.71	1.20	1.04
2.0	(10)	2.49	0.42	1.18	1.07
7.1	(5)	0.63	-	-	-
16.0	(6)	0.26	0.44	0.48	0.54
22.0	(7)	0.60	0.21	0.49	0.26
South					
11.0	(4)	0.22	0.44	1.04	-
South-Southwest					
3.4	(12)	0.60	1.1	1.24	0.54
4.0	(1)	0.55	0.91	1.24	0.38
12.2	(2)	0.38	-	0.47	0.70
31.7	(3)	0.38	0.46	0.45	0.37
74.2	(9)	0.46	0.39	0.73	0.36
Northeast					
29.5	(13)	0.55	0.57	0.43	0.79

Appendix IX: Percent sulphur* in Inco Limited stack particulates, Thompson, Manitoba, 1982-1985

Year	Nov.	Dec.	Jan.	Feb.	Aug.
81/82	-	7.2%	10.4%	8.5%	8.7%
82/83	-	-	-	7.2	7.2
83/84	9.1	8.9	7.2	7.3	8.1
84/85	8.8	10.5	11.1	11.3	10.4

* Extracted from mass balance calculations in monthly reports of emissions submitted by Inco Limited to Environmental Management Branch, Environment and Workplace Safety and Health, Province of Manitoba.

Appendix X: Mean pH of snow, Thompson, Manitoba, March samples, 1982-1985

Distance (km)	(Site)	1982	1983	1984	1985
Southeast					
1.4	(11)	6.39	4.96	6.23	5.29
2.0	(10)	6.18	5.13	5.39	4.89
7.1	(5)	5.96	-	-	-
16.0	(6)	5.38	5.21	5.21	5.70
22.0	(7)	5.00	5.14	5.89	5.18
South					
11.0	(4)	5.16	5.24	7.23	-
South-Southwest					
3.4	(12)	6.33	5.13	6.75	5.10
4.0	(11)	5.82	5.04	5.33	5.07
12.2	(2)	5.26	5.04	6.28	5.15
31.7	(3)	6.37	5.12	6.87	5.21
74.2	(9)	5.18	5.67	6.91	5.04
Northeast					
29.5	(13)	6.47	5.92	6.64	7.00